

WHRP GEOTECHNICS REQUEST FOR PROPOSAL

I. PROBLEM TITLE

Effective Depth of Soil Compaction in Relation to Applied Compactive Energy

II. BACKGROUND AND PROBLEM STATEMENT

The Wisconsin Department of Transportation (WisDOT) spends approximately 10% of the improvement project budget on embankment construction each year. A critical aspect of embankment construction is to bring the embankment into a stable state that will provide an acceptable foundation for pavement construction and will contribute to the long-term performance of the pavement structure. To achieve this end, WisDOT has developed specifications for embankment density. It has also developed specifications to limit the thickness of embankment lifts placed during construction. The current specifications limit lift thickness to 8 inches for most soil conditions. However, if granular soils are used and density measurements are being made, a 12-inch lift thickness may be allowed. The 8-inch lift limit is by far the most common application on Departmental projects.

The 8-inch lift limit has been the standard for WisDOT construction for many years. This limit was based on practical field experience with contractor methods and equipment. It has been accepted as a reasonable soil thickness that would contribute to adequate embankment compaction without excessive testing and inspection by WisDOT staff.

Application of the specified 8-inch lift limit to embankment construction has raised a number of concerns and issues. Limiting lifts to 8 inches has a direct impact on contractor time and cost for embankment construction. WisDOT does not have the staff to closely monitor embankment construction. As a result, it is not uncommon to see embankment lifts of more than 8 inches on many WisDOT projects. This has raised concerns about the adequacy of embankment compaction. However, it has been many years since WisDOT has examined the limit on lift thickness. Over that time, normal earth moving equipment has become larger and heavier and is thought to impart greater energy to the subgrade during construction. Also, specialized high-energy compaction equipment has been developed by a number of equipment manufacturers. This equipment is advertised as being capable of compacting a soil layer of up to 6 feet in thickness. While WisDOT has not examined these conditions or claims, it brings into question the need to maintain the required 8-inch lift limit for embankment construction.

WisDOT recognizes the need to review our policies and requirements for lift thickness based on current construction practices and equipment. However, any changes to our current requirements must be based on sound theoretical analyses and actual field monitoring. WisDOT proposes to enter into a study with the following aims and goals.

- 1) Conduct theoretical analyses to relate degree of soil compaction at various depths below the surface to energy applied to the surface.
- 2) Develop a system to monitor energy received and degree of compaction achieved at various depths under actual field conditions.
- 3) Develop processes to determine the influence of basic soil parameters such as texture, plasticity, and moisture content on energy dissipation and compaction achieved.
- 4) Develop recommendations to optimize lift thickness with practical considerations for equipment availability and delivered energy.

III. SCOPE

This study can be separated into three phases. In the first phase, the researcher must obtain and review available literature pertinent to this study. This would include academic research, policy and practices of other state highway agencies, and manufacturer literature and research. This information should be applied to the second phase of theoretical/lab analyses to relate depth, degree of compaction, applied surface energy, and soil properties. Investigated compactive forces should be based on typical construction equipment used by Wisconsin grading contractors. Results of the first two phases will be presented to the Department in summary report. The results of these phases will also guide the third phase, which involves the development of methods to measure responses and results under actual embankment construction conditions/project(s). This will include investigation of various soil types and conditions. The fourth phase will consist of an analysis of the gathered data to relate actual field responses to the theoretical responses, development of predictive methods to relate applied energy to degree of compaction at depth, and recommendations for an optimum lift thickness of WisDOT embankment construction. All data, findings and conclusions would be presented in a final report.

IV. SPECIFIC RESULTS, FINDINGS, TOOLS, ETC.

This research effort will produce needed data and analyses to provide an objective examination of appropriate lift thickness limitations on WisDOT embankment construction projects. The results of this study will relate applied surface energy to degree of compaction achieved in various soil types and moistures, at increasing depths. This will allow WisDOT to determine if revisions to its current specifications relating to lift thicknesses are necessary or desirable. This study has the potential to improve efficiency of construction operations and reduce construction costs. It also has

the potential to improve construction operations to deliver a more stable subgrade. A final report will be required documenting all research findings and conclusions.

V. LENGTH OF RESEARCH PROJECT AND APPROXIMATE COST

It is estimated that that the time required for this project should not exceed 2 years. The estimated cost should range between \$45,000 and \$55,000. Time and cost estimates supplied in the research proposals will be evaluated by the TOC as part of the selection criteria.

VI. URGENCY AND POTENTIAL BENEFITS

WisDOT has not examined the issue of lift thickness and adequate compaction for many years. Changes in equipment size and introduction of improved compaction equipment may have changed the effective depth at which adequate compaction can be achieved. However, any change from current practice must ensure that subgrade compaction quality is maintained. Increasing lift thickness has the potential to speed embankment construction and reduce costs. Developing methods to relate applied surface energy to achieved compaction has the potential to improve subgrade construction.

VII. ADDITIONAL REQUIREMENTS FOR IMPLEMENTATION

The results of the study will produce an objective analysis to determine an optimal lift thickness for embankment construction on WisDOT projects. Any changes from current practices will need to be incorporated into the WisDOT Standard Specifications for Highway and Structure Construction. This work is beyond the scope of this research effort.

WHRP_Lifts.doc



Transportation Literature Search

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Applied Energy and Effective Depth of Soil Compaction

Prepared for
Wisconsin Highway Research Program
Geotechnics Technical Oversight Committee

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Transportation Literature Searches are prepared for WisDOT staff and principal investigators to heighten awareness of completed research in areas of current interest. The citations below are representative, rather than exhaustive, of available English-language studies on the topic. Primary online resources for the literature searches are OCLC's [WorldCat](#) and [TLCat](#), U.S. DOT's [TRIS Online](#), the National Transportation Library ([NTL](#)), TRB's Research in Progress ([RiP](#)) and other academic, engineering and scientific databases as appropriate. Links to online copies of cited literature are noted when available. Hard copies may be obtained through the WisDOT Library at library@dot.state.wi.us or 608-264-8142.

SUMMARY

In our search of the above databases we found six articles and reports that pertain to applied energy and effective depth in the compaction of soils, thick lifts or otherwise. Of these, four were articles in academic journals and conference proceedings, one was a report from Texas A&M University, and another was an article in a federally published journal. Two of these documents were published in 2005, and one each in 2004, 2003, 2001 and 2000.

KEYWORDS

Compaction, soil, effective, depth, applied, energy, compactive, thick lift, density.

CITATIONS

Title: Effect of dynamic compaction on placement of high-road embankment

Author(s): Wei-Lie Zou, Zhao Wang, Zheng-Fa Yao

Date: November 2005

Doc ID/URL: *Journal of Performance of Constructed Facilities*, Vol. 19 (4), November 2005: 316-323.

Description: 8 pp.

Contents: This case history presents an application of dynamic compaction in placement of a road embankment with a height of 41 m on the Yuncheng-Sanmenxia Expressway, Shanxi Province, China. The monitoring results during the compaction and the long period after compaction are analyzed and compared with those from compaction by rolling. It is obvious that dynamic compaction has such advantages as a high degree of compaction, a wide suitable range of placement water content (7-19%), and quick construction (over 4 m lift thickness) and can be applied in many high-fill engineering projects. In addition, application of a fabric-enclosed sand drain for treatment of an overl soft foundation for a road embankment is also introduced.

Title: Impact of compaction energy on soil engineering properties

Author(s): Isaac Drew, David J. White

Date: 2005

Doc ID/URL: *Proceedings of the 2005 Mid-Continent Transportation Research Symposium*, 2005: 1.

<http://www.ctre.iastate.edu/pubs/midcon2005/drewcompactionabstract.pdf>

Description: 1 p.

Contents: Strength and deformation parameters of a compacted soil are known to be related to soil type and moisture. However, little attention has been directed towards understanding the influence of compaction energy on soil type and moisture. This paper describes a laboratory study conducted to evaluate the relationship between soil type, soil moisture content, and compaction energy on five cohesive soil types. Specimens were compacted with impact energy at levels of 355, 592 (standard Proctor), 987, 1643, and 2693 kJ/m³ (modified Proctor) over a wide range of moisture contents to determine dry unit weight, unconfined compressive strength, and the secant (50% strain) stiffness. In total, 125 Proctor tests and 95 unconfined compression tests were performed. At each energy

level, a soil specimen was tested at four to five moisture contents with respect to its standard Proctor moisture range. In addition, 48 consolidated undrained triaxial tests were performed at the five energy levels and four moisture content levels for a silt to evaluate changes in effective stress shear strength parameters. This paper summarizes the results of statistical analyses performed on all tests conducted. The models that best explain variability in dry unit weight, strength, and stiffness are presented. Models are presented for each individual soil type and for all soils grouped together. Independent variables used in the modeling include compaction energy, moisture content, Atterberg limits, material passing the No. 200 sieve, and clay fraction. Results show that compaction energy is a key factor in determining soil strength and stiffness parameters and should be considered during the planning phase of any earthwork construction operation.

Title: Effect of an innovative vertical vibro-tracked vehicle on soil compaction

Author(s): D.T. Tran, T. Muro

Date: 2004

Doc ID/URL: *Journal of Terramechanics*, Vol. 41 (1), 2004: 1-23.

Description: 23 pp.

Contents: The aim of this paper is to compare a new vertical vibro-compaction machine, carried by a tracked vehicle of total weight 10.9 kN, with compactors using centrifugal, vertical and horizontal oscillators at the exciting force of 9.8 kN and at a frequency of 16 Hz. These were tested experimentally on a thick lift of decomposed weathered granite sandy soil. It was observed that the final amount of sinkage of the terrain surface using the vertical vibro-tracked vehicle was the greatest. The final distribution of dry density was almost uniform in depth and the values were the largest of all other maximum dry densities for centrifugal and horizontal vibro-tracked vehicles. As a result, the vertical vibro-tracked vehicle was verified theoretically from the analysis of the stress and the acceleration propagation to be an excellent and impressive new compaction machine for compacting thick lifts of soil stratum.

Title: Intelligent Compaction: Overview and Research Needs

Author(s): Jean-Louis Briaud, Jeongbok Seo

Date: December 2003

Doc ID/URL: Texas A&M University, 2003.

http://www.webs1.uidaho.edu/bayomy/trb/afh60/IntCompaction_Briaud_September2004_.pdf

Description: 69 pp.

Contents: There are a number of research needs which have to be addressed before intelligent compaction can reach its full potential in the USA. a) Demonstrate that intelligent compaction leads to better compaction than conventional compaction. Costs differences between the two techniques should be documented. b) Understand the interdependence between the modulus and the water content, as well as the shape of the modulus versus water content curve. c) Develop a simple laboratory test to obtain ahead of time the target modulus from a modulus versus water content curve; this target modulus must be verified in the field using the same test. d) Study the depth of compaction that can be achieved by various rollers for various soils. e) Study existing specifications and draft standard specifications for the USA. An approach is proposed which satisfies the ideas developed above. It consists of running the usual Proctor test in the laboratory but adding the Briaud Compaction Device test (BCD lasts 2 seconds) on top of the soil in the mold to get the modulus. This gives the target values. In the field, the instrumented roller performs intelligent compaction and is checked at chosen intervals with the BCD. The advantage of the BCD is that the same test can be run in the lab and in the field in very little time.

Title: Wetting-induced settlement of compacted-fill embankments

Author(s): G.A. Miller, K.K. Muraleetharan, Y.Y. Lim

Date: 2001

Doc ID/URL: *Transportation Research Record 1755*, 2001: 111-118.

Description: 8 pp.

Contents: Many highway embankments experience problematic settlements. Compression of soil under the self-weight of the embankment generally occurs during construction, but postconstruction, wetting-induced collapse can result in more long-term settlement problems, depending on climate and movement of the wetting front. A study undertaken to examine settle. ment associated with unsaturated soil embankments included centrifuge modeling of compacted silt embankments, laboratory testing of the embankment soil, and data interpretation with the focus on settlement prediction. A silty soil was selected to facilitate the measurement of matric suction using tensiometers. Three model embankments were constructed and tested in the Army Corps of Engineers Centrifuge Research Center in Vicksburg, Mississippi. Embankments 20 m high were simulated using centrifugal acceleration of 165 g. Embankments were constructed to achieve a relative compaction of 90 or 95 percent based on standard effort and moisture content between 2 and 5 percent dry of the optimum moisture content. Instrumentation used during self-

weight compression and wetting included linear variable differential transformers and pore-pressure transducers equipped with high-air-entry porous stones. Results demonstrate the importance of the as-compacted water content and dry unit weight on the potential for wetting-induced collapse settlement. Settlement caused by self-weight compression and that caused by wetting-induced collapse are clearly discernable in results of centrifuge tests, allowing for comparison to settlement predictions. Results are discussed in light of typical compaction specifications, oedometer-based predictions, and implications for the design of compacted embankments.

Title: Mechanical behaviour of a sand bed subjected to low energy dynamic compaction, modelled in a geotechnical centrifuge

Author(s): M. Parvizi, C.M. Merrifield

Date: 2000

Doc ID/URL: *Journal de Physique IV: JP*, Vol. 10 (9), 2000: 131-135.

Description: 5 pp.

Contents: This paper describes the design and operation of a unique model compactor simulating the process of low energy compaction in a geotechnical centrifuge. This study was undertaken at 20 g using a tamper mass of 875 gm falling through 100 mm onto a stiff aluminum target, having a mass 268 gm and a diameter of 100 mm. Applying standard geotechnical centrifuge scaling laws, this simulated a field scale tamper mass of approximately seven tonnes falling through two meters onto a target having a base area of 3.14 m². Using the WAK Test method, developed to evaluate improvement in soil mechanical characteristics due to dynamic compaction, an estimate was obtained of the change in stiffness, damping coefficient, mass of vibrated soil and effective depth of influence with increasing number of blows. The soil dynamic response to each blow was measured by an array of accelerometers and earth pressure cells embedded in the soil mass. Analysis in the time domain of the dynamic load cell and accelerometer data showed improvement of soil mechanical behaviour per blow in terms of peak particle velocity and dynamic peak pressure against time of arrival. The rate and efficiency of improvement was clearly demonstrated by the relationship of peak particle velocity and dynamic peak pressure with blow number. Likewise the WAK Test was shown to be a reliable indicator of process success.